Case Study of a Pond Monitoring System and Supplemental Mechanical Aeration at a Small-Scale Aquaculture Farm

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Abstract

A demonstration project showcased two potentially energy-saving technologies for use with small-scale aquaculture, a pond monitoring system and supplemental mechanical aerators. This equipment was installed and evaluated over two growing seasons at a two-pond, inland shrimp farm in Central Alabama. The pond water quality and energy usage were recorded, and the energy consumption was compared to determine the energy savings of using the equipment. The equipment proved to be effective at preventing losses when used in a risk management mode and was effective at maintaining the pond water quality. It was concluded that such equipment would be useful if it is cost effective.

Keywords: Aquaculture, mechanical aeration, paddlewheel aerator, pond monitoring system

1. Introduction and Background

1.1 Mechanical Aeration and Water Quality in Aquaculture Ponds

The effects of aeration on aquaculture water quality have been studied for over thirty years. Rogers (1989) examined aeration and circulation for effective aquaculture pond management, defining these two separate processes as both greatly affecting pond dynamics. Rogers found that aeration, or the addition of supplemental oxygen to the pond water, provides adequate aerobic conditions to support aquatic life and improve water quality. It was concluded that both aeration and circulation were necessary to prevent the natural aging of pond soil condition and water quality.

Hopkins, Stokes, Browdy, and Sandifer (1991) examined intensive shrimp ponds to find the relationship between feeding rate, paddlewheel aeration rate, and expected dawn dissolved oxygen. Hopkins found that the determination of the proper level of supplemental aeration is critical for maintaining adequate concentrations of dissolved oxygen while minimizing equipment and operating costs. The results indicated that that dawn dissolved oxygen can be predicted based upon the amount of feed applied per unit aeration.

Boyd (1998), in a seminal work, summarized the, then, ‘state of the art’ of mechanical aeration of aquaculture ponds. Boyd found that paddlewheel aerators and propeller-aspirator-pumps were probably the most widely used in ponds. Boyd also found that automatic devices used to start and stop aerators in response to daily changes in dissolved oxygen concentrations were improving, but, at that time, were expensive and not completely reliable. Boyd also found that augmentation of natural supplies of dissolved oxygen in ponds often was necessary to prevent stress or mortality of fish and crustaceans when dissolved oxygen concentrations were low. Boyd concluded that mechanical aeration was by far the most common and usually the most effective means of increasing dissolved oxygen concentrations in ponds.

McGraw, Teichert-Coddington, Rouse, and Boyd (2001) conducted a field study with nine 0.11-ha earthen ponds that were stocked with two species of *Litopenaeus* shrimp postlarvae. The ponds were equipped with automated temperature and dissolved oxygen concentration data acquisition devices. In the study, aspirator-pump aerators were automatically activated when the dissolved oxygen fell to 65% (4.6 mg/l), 40% (2.8 mg/l), or 15% (1.1 mg/l) of saturation. They found that the mean shrimp yield, survival of both species, and profitability increased linearly as minimum dissolved oxygen concentration increased from 15% to 65% of saturation. It was also found that higher yields were positively correlated with higher survivals. They concluded that the final mean shrimp weights were not significantly affected by minimum dissolved oxygen concentrations.

Kumar, Moulick, and Chandra-Mal (2013) noted that aeration represented the third largest production expense in intensive aquaculture ponds at about fifteen percent of the total cost. They examined the economic performance of five different aeration systems, which were the circular stepped cascade, pooled circular stepped cascade, 1-hp paddle wheel, 2-hp paddle wheel, and the propeller aspirator pump aerators. The aerators were evaluated and compared at different pond sizes, initial dissolved oxygen concentrations, and operating hours, where the stocking density and feeding was typical for the culture of Indian major carp. For pond sizes more than 5,000 cubic meters, it was found that the 1-hp and 2-hp paddle wheel aerators were found to be efficient.

1.2 Pond Monitoring Systems

In small-scale aquaculture, as with any enterprise, the key to being successful is to keep revenues high and costs down. Mechanical aeration, the process whereby the water is supplied with oxygen, is one of the largest continuous expenditures. It is integral because the amount of oxygen in the water effects the size, quality, health, and survival of the shrimp (McGraw, Teichert-Coddington, Rouse, & Boyd, 2001). The cost of aeration depends on the amount of time the aerator is operated; however, pond monitoring equipment systems have the ability to efficiently control aeration. Also, the type of aerator also has a great effect in terms of its electrical efficiency (Kumar, Moulick, & Chandra-Mal, 2013).

Pond monitoring systems typically include three main components: a control unit, sensors, and an interface. The control unit collects information from the sensors, turns equipment on and off, and connects to the interface through which it receives information from the human operator, in this case, from the farmer. The control unit is connected to the sensors and the equipment activators through wiring or wirelessly and is usually contained in a housing. The sensors are placed at strategic locations in the pond to make readings of a certain quantity and transmit those readings to the control unit. The sensors, which may be large or very small, are designed for the environment in which they are to be used. The interface is designed for control by the farmer and may be as simple as an LCD screen on the control unit housing with a few buttons or may be designed to be on a displayed on a computer or a portable device. The control unit interface allows the farmer to either control equipment operation manually or to set the operation protocols.

2. Demonstration Site and Equipment

2.1 Site Description

The demonstration site was located on an inland shrimp farm in the central portion of Alabama. Inland shrimp farming was once regarded as a potentially viable and lucrative form of aquaculture in Alabama due to the perception of it having a moderate risk and potentially considerable profits. This small-scale farm included two catfish-style ponds, each approximately 2.5 acres (~1 hectare). The water was sourced from a well that drew from a high-salinity aquifer, most suitable for the cultivation of shrimp (and relatively unsuitable for human consumption). The ponds were typically filled in the spring and stocked with shrimp post-larvae; the harvest was gathered in the fall by draining the pond through an outflow pipe into mesh baskets. Each pond was originally outfitted with an appropriately-sized, 10-HP (7.5-kW), paddlewheel aerator, which, prior to the study, was operated manually. The farmer used a handheld dissolved oxygen meter to determine the need for and duration of aerator operation.

2.2 Pond Monitoring System

The pond monitoring system studied was the Suncoast Systems, Inc. (Pensacola, FL) Oxygen Scan Control Alarm and Report (“O.S.C.A.R.”) System. This lower-cost, comprehensive aeration management tool had been shown to produce significant energy savings in on-farm use. The system included a control unit intended for outdoors use, sensors on a float, and an interface on a customized desktop computer (Figure 1 (a)).

Figure 1. Suncoast Systems, Inc. O.S.C.A.R. pond monitoring system (a) and its components: (b) control unit in housing; (c) float with sensors, and; (d) interface software.

(a)

(b) (c) (d)

2.2.1 Control Unit

The control unit consisted of several electronic boards and components that were contained in a sealed, weather-resistant housing that was mounted on a post at the pond side (Figure 1 (b)). There were connectors for the sensor and equipment activator wiring on the control unit, with ports for the wiring through the underside of the housing. The control unit was connected to the sensors, which were on a float, and to the paddlewheel aerators by thin, heavily-insulated wires. However, the control unit was connected wirelessly by radio to the interface. On the front of the control unit housing was a small LCD screen that could give the dissolved oxygen level, water temperature, and aerator operation status by pressing buttons that were on the outside of the housing. The aerators could also be activated manually at the control unit.

2.2.2 Sensor Float

The sensors were mounted under a float that had solar panels for power on the top (Figure 1 (c)). It was positioned in the pond close to the side where the control unit was mounted, anchored by a weight. The wires that connected the control unit to the sensor float ran through shallowly-buried, small-diameter PVC pipes that spanned from the base of the mounting post to the pond berm at the water's surface. The sensors measured the dissolved oxygen concentration in milligrams per liter (mg/L) and the temperature. The farmer typically validated the system sensor readings with a handheld dissolved oxygen/temperature sensor.

2.2.3 Interface

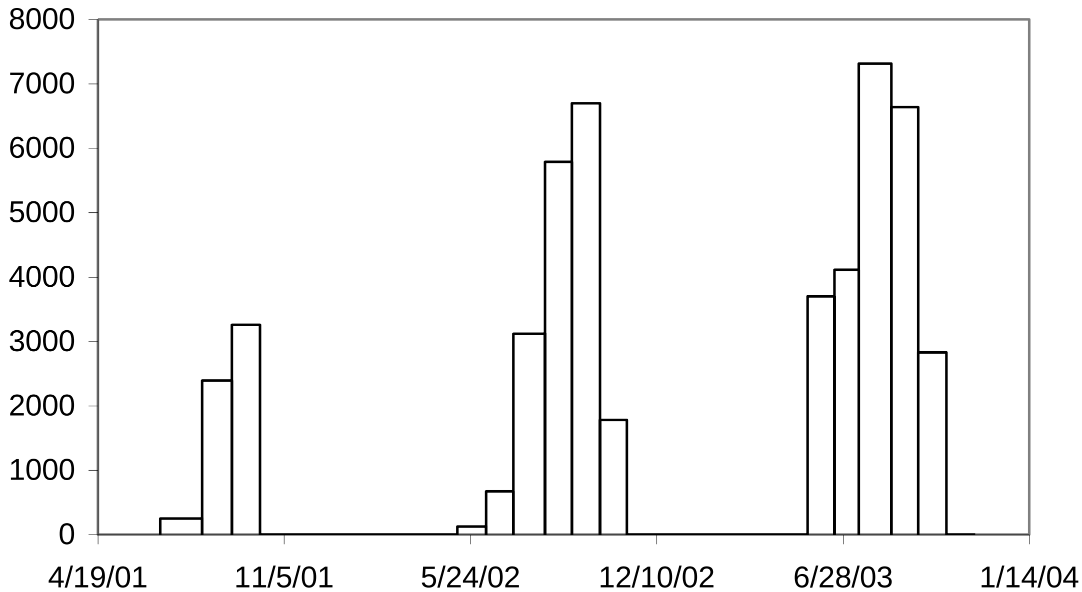
Although the control unit had some limited functions through the small LCD screen and buttons on the housing, the system included a Windows-based computer with interface software (Figure 1 (d)). The interface software was pre-installed on a customized desktop computer, which included a tower CPU, monitor, keyboard, and mouse, supplied as part of the system. The software was connected to the control unit wirelessly by hardware in the tower, and it displayed the current dissolved oxygen, water temperature, and aerator operation status. However, the primary function of the interface software was to allow the farmer to set the desired dissolved oxygen level or the times at which the aerators would be turned on and off. The sensor data were also collected by the computer and graphs of the data over time could be displayed. These data could also be exported to a spreadsheet program.

The interface software included an alarm that could sound through the computer's speakers in the event of low dissolved oxygen or equipment malfunction. To protect against power outages, computer interface was supplied with an uninterruptable power supply.

3. Method

3.1 Equipment Installation and Data Collection

Figure 2. Aeration energy consumption readings in kilowatt-hours for 2001 – 2003



The installation of two 5-HP (3.7-kW) supplemental aerators took place on June 3, 2004, one for each pond. This was necessary before the pond monitoring system installation, The Suncoast Systems O.S.C.A.R. pond monitoring system (Figure 1) was installed on June 24 and 25, 2004. The data from the monitored period shows the water temperature and dissolved oxygen concentration, as well as aerator start and stop times, amperages, and any alarms. The Suncoast Systems O.S.C.A.R. pond monitoring system recorded energy consumption data from both ponds from the date of installation, June 25, 2004. The equipment was stored between the seasons, and the data were compiled with the energy cost records. The risk management and energy consumption records were compiled, and the usage data was analyzed.

3.2 Study Conditions and Comparisons

Observation of the two ponds in May and early June of 2004 suggested that they were not identical. This was confirmed by the farmer's daily records of temperature, dissolved oxygen, and condition differences between the ponds for the last three seasons. Therefore, neither of the ponds could appropriately be used as a "control" or farmer-managed pond, as originally intended. The decision was made to instead evaluate the energy consumption and production data from the previous three years with the data gathered in 2004 and 2005 from system-controlled ponds.

3.3 Pond Monitoring and Aeration Control Strategies

The pond monitoring system was set up to control aeration in both ponds. The farmer, however, was responsible for determining how the system controls the aeration. Each pond included one primary 10-HP (7.5-kW) aerator and one supplemental 5-HP (3.7-kW) aerator. The usage of aerators followed a plan negotiated with the farmer for this initial year:

(1) the primary aerators were controlled by the farmer;
(2) the supplemental aerators were controlled by the monitoring system, and;
(3) the primary aerators were used midday for pond dissolved oxygen destratification.

This was primarily a risk management-style strategy.

An energy-saving aerator usage strategy was promoted and negotiated with the farmer for the second growing season. This energy-saving strategy entailed the following:

(1) the primary aerators would continue to be farmer-controlled with use of the system timer, however, there would be a decrease of use for shorter durations (< 6 hr.) and for dissolved oxygen destratification, and;

(2) the supplemental aerators would continue under monitoring system control with a decrease of short or long use durations (< ½ hr., > 6 hr.), (which may have been a software issue) with near-exclusive use for midday dissolved oxygen destratification.

This strategy would put in to practice a recommendation that the activations of primary and supplemental aerators should be minimized, and the duration of aeration should be specific to the aerator with the idea that pond monitoring systems can be used effectively with good management. The farmer was made aware of the recommendations; however, the frequent pond monitoring equipment outages did not permit this task to be accomplished

4. Results

4.1 Growing Seasons and Pond Monitoring System Inactivity

The growing season in the first year, from stocking on May 10, 2004 to the last harvest on October 7, 2004, lasted a total of 150 days. The pond monitoring system was in operation during the last two-thirds of the season, 105 days, barring any power outages, effects of hurricanes, or computer malfunctions. In the first season, the farmer controlled the timing of aeration from evening to morning and the monitoring system was used primarily for risk management. It governed the timing of supplemental aeration with 5-HP (3.7 kW) aerators when needed and monitored the amperage for all aerators. As the season progressed, the supplemental aerators were initiated more and more often, as expected. In terms of the amperage recordings, the system proved to be invaluable. In fact, the impending breakdown of an existing 10-HP (7.5 kW) primary aerator was detected and averted, saving the farmer several thousand dollars.

In the second season, the pond monitoring equipment was inactive for a large portion of the time due to frequent power outages and damage caused by lightning electrical surges. Suncoast Systems technicians made several visits to repair and replace components. The possibility of obtaining a surge protector was investigated to protect the monitoring equipment. Consequently, because of the damage, the farmer controlled the timing of aeration from evening to morning exclusively.

4.2 Historical Energy Consumption

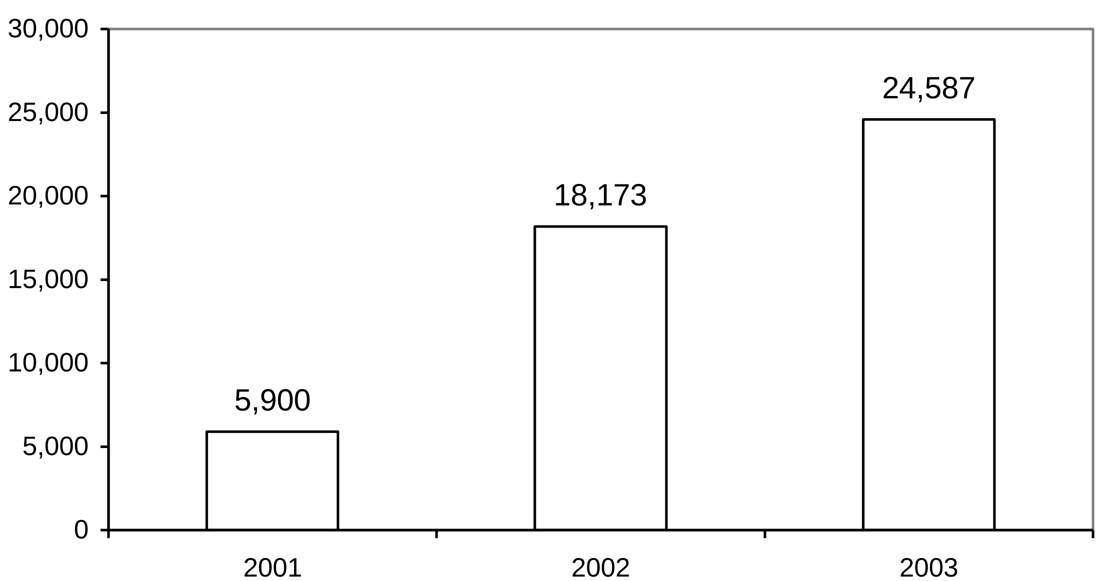


Figure 3. Totals of energy consumption readings in kilowatt-hours for the seasons

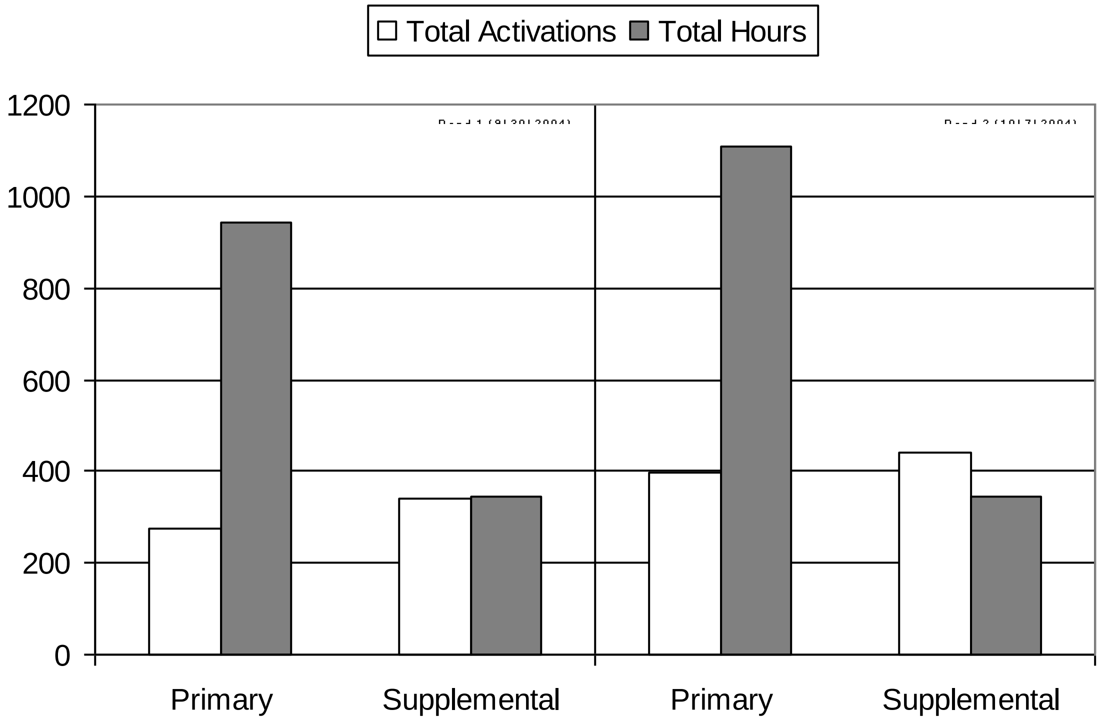


Figure 4. Total activations and total usage hours for the two aerators in both ponds

The historical energy consumption records for the years 2001 through 2003 were collected (Figures 2 and 3). There were differences in the data due to changes in the aeration management practices and equipment in these first years of the farm's operation.

4.3 Aerator Activation, Usage Hours, and Energy Consumption

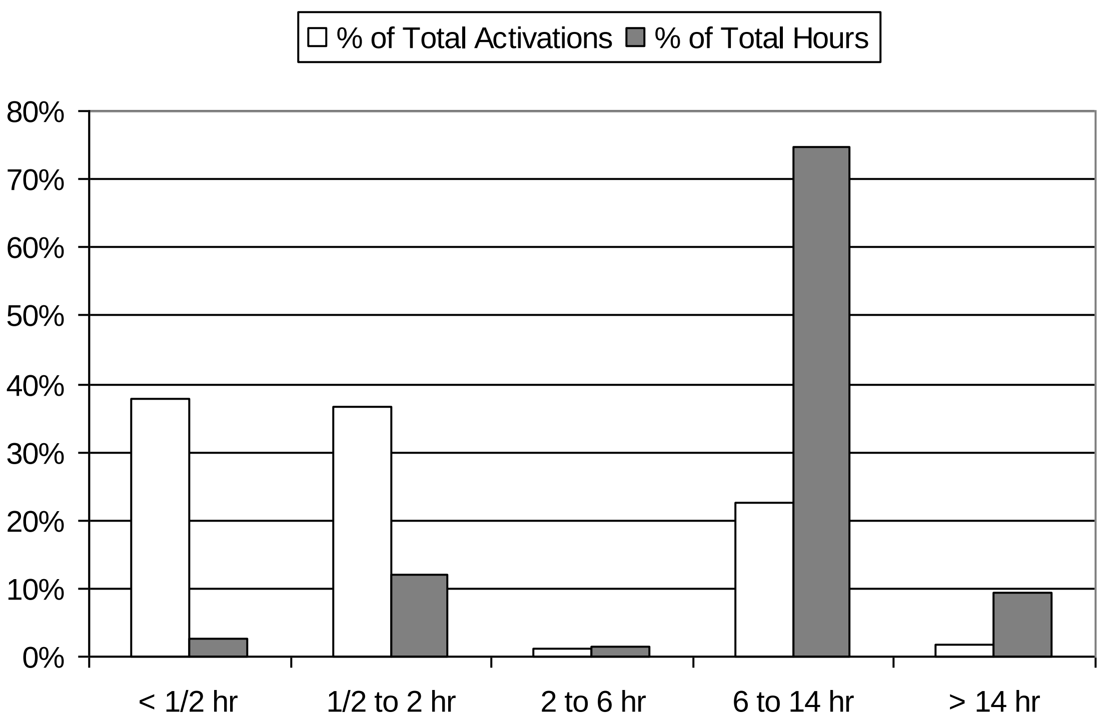


Figure 5. Percentages of activations and hours by duration for the primary (10 HP) aerators

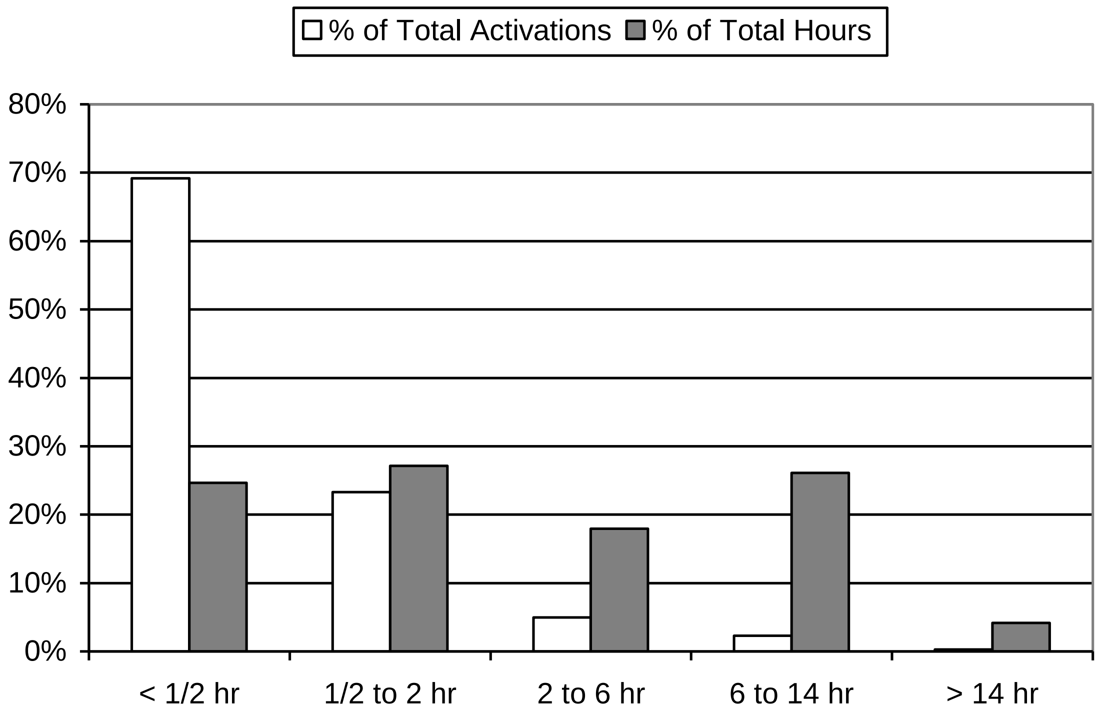


Figure 6. Percentages of activations and hours by duration for supplemental (5 HP) aerators

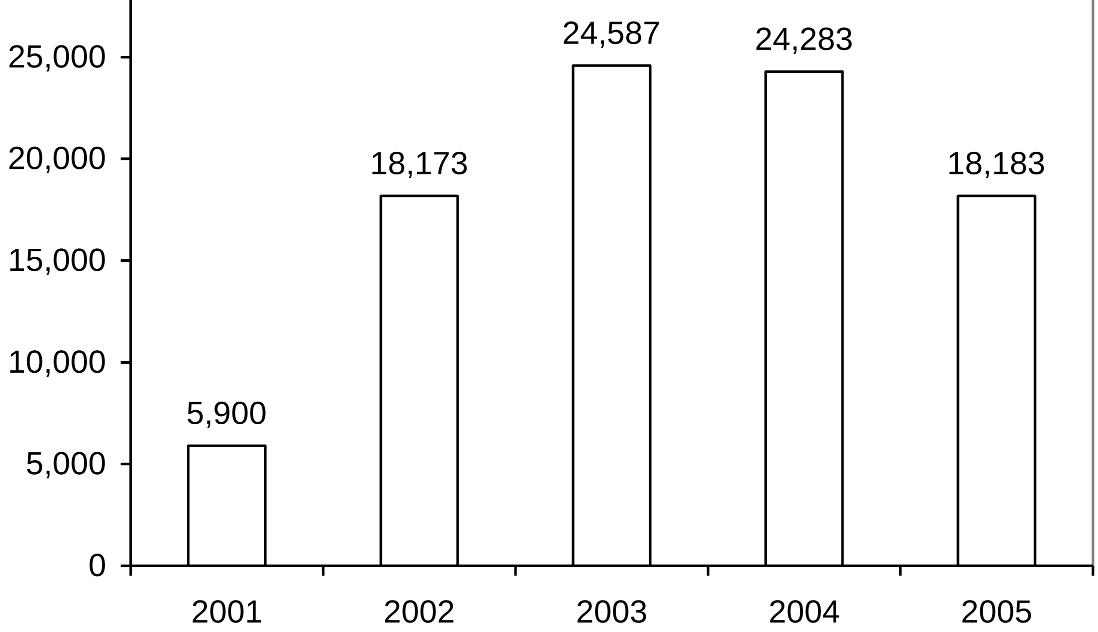


Figure 7. Totals of energy consumption readings in kilowatt-hours for 2003 - 2005

For the four aerators in the two ponds, the usage was also analyzed in terms of the number of times that the aerator was activated and the total time each aerator was used (Figure 4). For the primary 10-HP (7.5 kW) aerators, most of the usage time (~85%) was spent during longer, 6 or more-hour, nighttime intervals, as expected. However, most activations (~70%) were for short, less than two-hour, intervals (Figure 5). For the secondary 5-HP (3.7-kW) aerators, the majority (~90%) of the activations were for shorter, less than two-hour, intervals, as expected.

However, the incidences when they were used for longer, 6 or more-hour, nighttime intervals accounted for almost one-third of the total usage hours (Figure 6). The data for actual energy consumption (i.e., utility records) were collected (Figure 7).

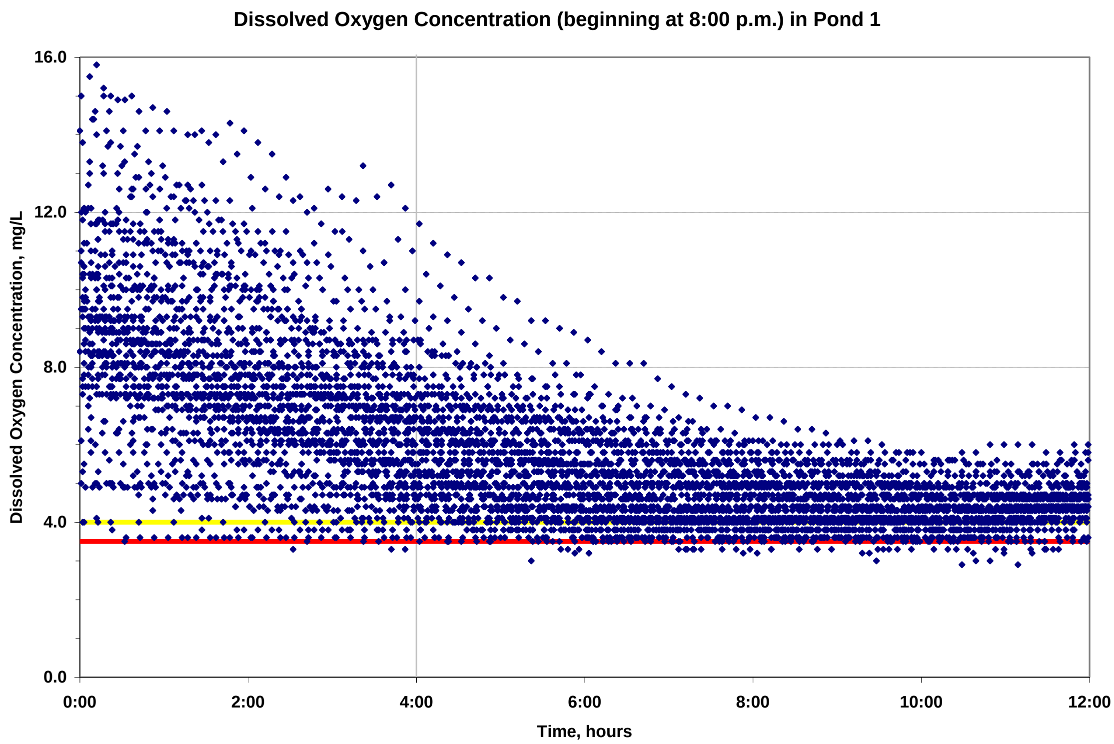


Figure 8. Dissolved oxygen concentration in the pond beginning at 8:00 p.m.

4.4 Dissolved Oxygen Concentration and Supplemental Aeration

The recorded dissolved oxygen concentration data for the evening to morning periods showed the expected decreasing trends for both ponds and the buffering of the trend due to aeration. The analysis of the concentration data showed that the control system was able to maintain the ponds at or above 4.0 milligrams of oxygen per liter (mg/L) for over 90% of the time, and supplemental aeration was necessary for dissolved oxygen maintenance.

The detailed data from the pond monitoring system showed that the supplemental aerators were activated often to avert excessive decreases in dissolved oxygen concentration. As a result of incorporating the supplemental aerators into this production system, the dissolved oxygen concentrations stayed above 4.0 mg/L for over 90% of the time. The dissolved oxygen concentrations over the entire recorded first season showed the expected decreasing trend from evening through the night and maintenance of the dissolved oxygen levels (Figure 8).

5. Discussion

From an informal comparison of the two seasons, it is noted that the aeration kilowatt-hours for the unmonitored second season in 2005 showed a dramatic decrease over the first monitored season in 2004. This is contrary to the ideas of having the ponds monitored, i.e. the monitored season should require less aeration than the unmonitored season. (Otherwise, it would be unnecessary to invest in this technology.) However, all factors between the 2004 and 2005 seasons were not equal. The aeration needs are dependent on stocking density, feeding regimen, and other management aspects (all which we assume to be roughly equivalent between the two years), but also on the weather. Aside from the prevalence of major weather events (i.e., hurricanes), the general climate was not the same between the two years. One measure of climate would be the average daily temperature, but these values were not found to be significantly different between the two years.

6. Conclusion

This case study showed that the use of a pond monitoring system combined with equipment to provide supplemental aeration is effective in maintaining suitable dissolved oxygen levels in small-scale pond aquaculture. Although permitting pond monitoring systems to fully automate the control of aeration equipment would likely be optimal, these systems are also effective as a tool to guide manual control of aeration. The former mode of operation would be for energy efficiency and the latter more for risk management. The results of the study also showed some evidence of a correlation between the weather conditions and the consumption of energy for aeration, which would be expected. It is concluded that these systems are effective at small-scale aquaculture farms and should be utilized where they are verifiably cost effective.

7. Acknowledgments

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